IAP P6/23
“Advanced Research on Exotic Nuclei for Nuclear Physics and Nuclear Astrophysics”
The Belgian Research Initiative on eXotic nuclie: BriX
Annual report 2008

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Partners:

Belgian partners:

- Katholieke Universiteit Leuven (K.U.Leuven)
  Instituut voor Kern- en Stralingsfysica (IKS)
- Université Libre de Bruxelles (U.L.B.)
  Physique Nucléaire Théorique et Physique Mathématique (PNTPM)
- Universiteit Gent (U.Gent)
  Theoretische fysica - Vakgroep Subatomaire en Stralingsfysica
- Studiecentrum voor Kernenergie (SCK • CEN)

EU partners:

- Grand Accélérateur National d’Ions Lourds (GANIL), France
- Gesellschaft für Schwerionenforschung (G.S.I.), Germany
- University of Köln (IKP), Germany
- Centre de Spectrométrie Nucléaire et de Spectrométrie de Masse, Orsay (CSNSM), France

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1. Research Activities

Introduction

Similar to last year's report, at the start of this annual report we briefly remind the aims and composition of the present network.

The proposed network brings together the Belgian expertise on theoretical and experimental nuclear physics, nuclear astrophysics and accelerator driven systems, and will execute, in a coherent and collaborative effort, a research program focussed around radioactive ion beam research. Together with the EU partners, a carefully selected sample of atomic nuclei most of them with extreme proton to neutron ratios will be studied to bring key elements for a better understanding of the manifestation of the strong, weak and electromagnetic interaction in the nuclear medium. Key experiments on the properties of exotic nuclei through decay, moment and reactivity measurements are proposed while the beta decay of specific isotopes will serve the weak interaction studies. Theoretical studies are directed towards few-body models, mean field descriptions and shell models and their symmetries. The results will be used for nuclear-structure studies, weak interaction studies and nuclear astrophysics, as well as to investigate fundamental nuclear physics aspects of accelerator driven systems.

The Belgian partners of the network are experimental groups from IKS-K.U.Leuven, U.Gent and SCK-CEN (Mol) and theoretical groups from U.L.B. (Brussels) and U.Gent. The EU partners are GANIL (Caen, France), GSI (Darmstadt, Germany), the Institute of Nuclear Physics of the University of Köln, UNI Köln (Köln, Germany) and the Centre de Spectrométrie Nucléaire et de Spectrométrie de Masse, CSNSM (Orsay, France).

Experimental campaigns and/or preparatory activities have taken place at the radioactive beam facilities of Louvain-la-Neuve (Belgium), ISOLDE-CERN (Switzerland), GANIL (France), GSI (Darmstadt) and K.V.I. (Groningen), and at the SCK•CEN and GELINA (Belgium) and ILL (France) neutron facilities. The major theoretical efforts were closely related to the experimental work in order to stimulate mutual feedback between theory and experiment.

Based on the expertise within the network and the importance of the scientific issues, this resulted in a number of work packages (WP). The report of the research activities is ordered according to the work packages as defined in the original proposal.

Progress report according to the work packages

Objective 1:
We want to increase the selectivity of the LISOL laser ion source and to optimise the experimental conditions at the Penning trap based WITCH (ISOLDE) and SHIPTRAP (GSI) projects.

	Workpackage 1: Preparation of radioactive ion beams	**Partners**
1	Optimisation of the LISOL laser ion source and development of new laser ionisation schemes	K.U.Leuven
2	Optimisation of the overall experimental conditions at SHIPTRAP related to studies along the N=Z line	K.U.Leuven – GSI

3.	Feasibility study to perform spectroscopy measurements with WICH and SHIPTRAP	K.U.Leuven – GSI

1.1

Laser ion source at LISOL

The crucial parameters of the laser ion source are its efficiency and selectivity. There are several sources of non-selective ionization in the laser-ionization zone; these are ion scattering of the primary beam creating a flux of energetic ions in the laser ionization zone and hard UV and X-ray radiation from the target/window material and from the buffer gas. The nuclear reaction products, especially in the case of fission, can also contribute to the weakly ionized plasma and unwanted ion creation in this zone. When the primary beam passes through the gas it transfers most of its energy to atoms via inelastic collisions. Most of the energy is deposited in the beam path but the scattered ions, the photons and energetic reaction products ionize the gas at larger distance from the point of initial ionization and low-density plasma is created far from the beam path. This causes recombination of laser-produced ions and thus reduces the ion source efficiency and the creation of unwanted ions. Collection of the unwanted ions prior to laser ionization using electrical fields is prevented due to the space-charge effect present in the gas cell. In order to avoid these unwanted ionization mechanism a 'shadow gas cell' was designed and constructed. The shadow gas cell for proton-induced fission consists of stopping and ionization chambers that are connected via an elbow channel. The stopped recoils are brought from the stopping volume to the laser ionization volume by the gas flow. Extended gas flow simulations were performed in order to make sure that this transport was free of turbulences. The laser beams enter the ionization chamber (30 mm long and 10 mm in diameter) longitudinally through a quartz window and ionize atoms along the chamber axis. This laser beam path was used to monitor the ion behavior in the ionization chamber. An extensive off-line and on-line experimental campaign took place to map the performances of the new system.

Heavy ion fusion evaporation reactions were used to produce neutron-deficient Rh isotopes. The total laser efficiency was comparable to the standard gas cells used but the selectivity was increased to >2200. This was due to the use of electrical fields in the laser ionization zone that allowed to collect all unwanted ions prior to laser ionization. The fact that the beam stopping volume was physically separated from the laser ionization zone, was essential as this reduced the creation of a weakly ionized plasma that prevents the use of electrical fields.

Light-ion induced fission reactions were used to produce neutron-rich Rh isotopes. As observed in previous cases, the laser ionization selectivity was much lower. Using the electrical fields, we could demonstrate that this is due to fission products that are deposited on the RF rods of the SPIG. When these radioactive atoms undergo beta minus decay they can be released from the rods and stopped in the pseudo potential of the SPIG. They are subsequently transported towards the mass separator and give rise to a strong non resonant background beam. We could definitely prove the existence of this mechanism by observing the production rate of specific isomers of 112Rh as well as of some heavier fission products by applying a positive DC potential on the SPIG rods and observing the suppression of the ion beam current. For stable nickel ions created in the ionization chamber, the reduction factor at a SPIG potential of 42 V is more than 1000. The reduction factor for laser-produced 112mRh is also more than 100. However, for 112gRh, the reduction is only 2 times. The latter is due to the fact that the radioactive mother 112Ru (0+ ground state) decays only to the 112gRh and not to the 112mRh state. A similar small reduction of factor 2 is observed for 142Ba, which has 142Cs as a parent nucleus with a Qß-value of 7.3 MeV and a lifetime of 1.7 s. A completely different situation is observed for the yield of 142Cs isotopes, which drops 55 times. This was explained by the fact

that the mother nucleus for Cs is Xe, which is a gaseous element and does not stick to the SPIG rods.

In-source laser spectroscopy

A great leap forward in the use of the gas cell for laser spectroscopy purposes has been achieved with the discovery of our ability to create photo-ions with good laser spectroscopy resolution in many different conditions, either outside the gas catcher in the radio frequency ion guide or at low pressure in the gas catcher itself. By sending the laser beam through the exit hole of the gas cell and applying a positive voltage on the SPIG rods to prevent ions from the gas cell to reach the SPIG, we were able to prove the feasibility of the so-called Laser Ion Source Trap (LIST) mode. The repetition rate of our laser system is however too small to be able to obtain a reasonable efficiency. The use of transverse laser light between the exit hole and the SPIG rods was also proven to be feasible. Note that both modes of operation result in a much narrower total laser line width as the pressure in these regions are much reduced compared to the situation inside the gas cell where pressures over 100 mbar are usually used.
We were able to perform in-source laser spectroscopy measurements on the Cu isotopes where the atomic ground-state splitting is large enough to overcome the Doppler, laser and pressure broadening. The magnetic moment of 57Cu and 59Cu was measured and the results of this experiment are reported in section 5.3. Other elements are currently under investigation for further studies.

1.2
No activity was performed in 2008

1.3
For WITCH two possible set-ups are being considered. The first is the installation of a tape station on top of the WITCH apparatus. In 2007 simulations have shown that this is feasible, but no further work was done for this.
We rather focused on the second set-up, i.e. a new and compact beta spectrometer consisting of a multi-wire drift chamber for electron tracking and a semiconductor detector for the energy determination. Such a combination allows one to reject events that were (back) scattered on the energy detector. Installing this spectrometer behind the WITCH Penning ion traps will, in addition, provide a scattering free source. Tests with a small prototype drift chamber with cubic symmetry have yielded good results. As simulations showed that a hexagonal geometry would be more favorable (e.g. to reduce scattering on the wires) a new prototype was developed. This is now being tested. Further, the materials to be used as window between the drift chamber and the energy detector were selected, while measurements to test the operation of a Si PIN diode in a He gas atmosphere and in electrical fields as will be present in the drift chamber are still ongoing.

Objective 2:
We want to model and analyse a selected set of nuclear reactions of astrophysics interest, including an experimental study of neutron-capture reactions.

	Workpackage 2: Study of reactions of astrophysics interest	**Partners**
1	Theoretical study of nuclear reactions of astrophysical interest: microscopic models, direct reactions and R-matrix analysis	U.L.B.

2	Theoretical and experimental study of neutron capture reactions of astrophysical interest	U.Gent – U.L.B.

2.1

Expansion of astrophysical S factor near zero energy in a microscopic model

Low-energy elastic phase shifts can be parametrized at low energies by effective-range expansions. Similarly, it is possible to parametrize the low-energy astrophysical S-factor for radiative-capture reactions with the first terms of its Taylor expansion. We have shown that microscopic resonating-group calculations can provide such an expansion rigorously. The first coefficients of the S-factor expansion near zero energy are derived by a direct calculation at zero energy, i.e. without extrapolation, in the generator coordinate version of the resonating-group method. This method is valid for both neutron and charged-particle captures. The parameters of the effective nucleon-nucleon interaction are kept from the similar work already performed for the effective-range expansion. An S-factor expansion consistent with existing data has been determined in this way for the 16O(n,γ), 16O(p,γ), 14C(n,γ), 3H(α,γ), 3He(α,γ) radiative captures. The results provide a simple parametrization of the radiative-capture cross sections at low energies.

The 18F(p,α)15O reaction

The cross section has been measured by the CSNSM group at Louvain-la-Neuve at very low energies (down to 400 keV). This reaction plays a key role in novae physics, but the reaction rate remains very uncertain. The main reason is that the cross section is affected by several low-energy resonances whose properties are poorly known (or not known at all). The PNTPM contribution in this collaboration was to perform an R-matrix fit of the S-factor, by including the new data, as well as previous data. In particular we have analyzed interference effects near the proton threshold.

2.2

A measurement of the 41Ca(n,α)38Ar reaction cross section has been started at the GELINA neutron spectrometer of the Institute for Reference Materials and Measurements (IRMM) in Geel. The measurements are performed at a 30 meter long flight path using the time-of-flight technique and they cover neutron energies from a few eV up to about 100 keV. The neutron flux is determined replacing the 41Ca sample by a 10B sample, based on the well known 10B(n,α)7Li reaction cross section. A Frisch-gridded ionisation chamber with ultra pure methane as detector gas is used for the detection of the α particles. Four prominent resonances and a dozen smaller resonances could be observed with good resolution in this energy region. The data taking is still ongoing.

Objective 3:

We want to investigate the properties of key states in light exotic nuclei, compare them with the theoretical models developed within the collaboration, and understand the possible influence on the reaction mechanism at energies around the Coulomb barrier.

	Workpackage 3: **Light exotic nuclei**	**Partners**
1	Experimental investigation of the structure of light nuclei	K.U.Leuven – U.L.B. - GANIL
2	Reaction studies around the Coulomb barrier	K.U.Leuven – GANIL
3	Development and exploitation of cluster models and experimental investigation of light exotic nuclei using beta decay and reaction studies	U.L.B. – K.U.Leuven

4	Development and exploitation of break-up models for intermediate and relativistic energy reactions with light exotic nuclei	U.L.B. – GSI

3.1

Single particle state in 19Na

The H(18Ne,p)18Ne(g.s.) and H(18Ne,p')18Ne*(2+, 1.887 MeV) cross sections have been measured at Louvain-la-Neuve at energies corresponding to the excitation energy range between 2 and 3 MeV. The presence of 19Na single-particle levels at these energies was first predicted by a microscopic cluster model. The elastic and inelastic data have been analyzed simultaneously by using the R-matrix method. Two new states in 19Na have been observed at centre of mass energies Ecm = 2.78 ± 0.01 MeV and 3.09 ± 0.05 MeV. Both resonances exhibit large widths in the 18Ne(2+)+p channel, and low branching ratios into the elastic channel. The reduced proton widths confirm the single-particle nature of these states, with a 18Ne(2+)+p structure.

Ground state moments of 11Li

The magnetic dipole and electric quadrupole moment of the one-neutron-halo nucleus 11Li have been measured to an order of magnitude better precision than before and have now been published. These values, along with the recently measured changes in mean square charge radii, provide a stringent test for various nuclear models. It seems difficult to reproduce in a consistent manner the increase in the quadrupole moment and the increase of the charge radius of the halo-nucleus with respect to those of its 9Li core.

Beta decay of 8B

The solar-neutrino detectors Super-Kamiokande, SNO and ICARUS are primarily sensitive to electron neutrino's, νe, from the β-decay of 8B. Neutrino oscilations are invoked to explain the presence of νμ,τ components in the measured flux. Such a solution implies the distortion of the measured spectrum of solar neutrinos with respect to the unperturbed one. Thanks to the increasing accuracy of the solar neutrino measurements, the differences between the two spectra can be used to set constraints on the parameters of neutrino oscillations.

The β-decay of 8B proceeds to a broad 2+ continuum structure in the 8Be daughter, which immediately breaks up into two α particles. The neutrino spectrum is reconstructed from the energy of the α particles. The measurement is particularly delicate at low energy, where systematic errors become important.

With the aim of improving on the existing data, we performed a measurement at the TRIμP (Trapped Radioactive Isotopes: μicro-laboratories for Fundamental Physics) facility at KVI (Kernfysisch Versneller Instituut) , Groningen, The Netherlands. The 8B nuclei were produced by impinging with a 55MeV/nucleon 12C beam delivered by the AGOR (Accélérateur Groningen-Orsay) cyclotron on a 5mm-thick 12C target.. The TRIμP separator was tuned to optimize the selection of the 8B ions, which were then implanted in a finely segmented silicon detector. Ion-by-ion identification was achieved by a combination of time-of-flight and energy loss techniques, using a thin ΔE detector placed in front of the implantation detector. Decays of 8B were selected as those events following an implantation of a 8B nucleus in the same pixel. With this method the full energy of the emitted α particles is recovered with almost 100% efficiency down to the detection threshold of about 200keV. An internal energy calibration was performed using the β-delayed α particles emitted in the decay of 20Na ions, which were also separately implanted in the detector. The stability was regularly monitored using standard a sources.

The results look very promising, with better statistics and a much lower threshold than previous measurements. For the extraction of the neutrino spectrum, the β-particles energy summing needs to be taken into account. The measurement of the β-decay of the mirror 8Li nucleus, performed with the same method at TRIUMF (TRI-University Meson Facility, Vancouver, Canada) will help evaluating this and other systematic effects.

Beta decay of 11Be
The analysis of the 11Be beta decay populated in the beta decay of 11Li (data obtained at TRIUMF using our calometric detection system) is ongoing. Preliminary results show a different population of the 7Li+α channels that are open in this decay compared to literature. The analysis is a joined effort between GANIL and K.U.Leuven.

3.2
No activity reported for 2009.

3.3
The 5H and 5He(T=3/2) nuclei
These nuclei have been studied in a microscopic three-cluster model (5H=3H+n+n and 5He=t+p+n, 3He+n+n). The wave functions are defined in the Generator Coordinate Method but using the hyperspherical formalism for the 3-body coordinates. These systems being unstable, even in the ground state, we have determined the energy and width by using the "Analytic Continuation in the Coupling Constant" (ACCC) method, based on Padé approximants.
For the 5H ground state we have found results consistent with the literature. We have extended the calculation to excited states. In a second step we have investigated the analog states in 5He. This approach requires the mixing of the t+p+n and 3He+n+n configurations to include properly the isospin. The computer times are therefore much longer than for 5H. We have predicted the properties of the 1/2+ (T=3/2) analog state in 5He.

The 12Be nucleus
We have studied the 12Be nucleus in a microscopic cluster model involving the 6He+6He and α+8He configurations, as well as some of their excited states. This work has been performed in collaboration with M. Dufour (IReS Strasburg) and represents an extension of a previous study limited to ground-state configurations. We have analyzed the band structure of 12Be, by focusing on "molecular" states. In a second step we have started an analysis based on the "No Core Shell Model" (NCSM) developed at Strasbourg. Both approaches applied to a common problem should provide useful information about the advantages and limitations of these models.

Ab initio calculations
Cluster models require the use of "effective" nucleon-nucleon interactions. To go beyond this approximation, and to use "realistic" forces, the cluster approximation has to be replaced by "ab initio" models. Different variants exist and are, until now, essentially applied to the spectroscopic of light nuclei (typically up to A=12). In collaboration with S. Aoyama and Y. Suzuki (Niigata, Japan), we have started ab initio calculations of d+d elastic scattering.

Analytical properties of the two-body elastic scattering matrix
We have established the condition under which a two-body loosely bound state has an influence on low energy elastic scattering properties. For that, the interaction

potential should have a short enough range. Several examples illustrating this behaviour have been studied and, in cases where such influence exists, two general relations between scattering and bound-state properties have been established. The first relation, based on the position of the scattering matrix pole in the complex wave number plane, relates the effective-range expansion with the binding energy. The second relation, based on the residue of this pole, relates the effective-range expansion to the asymptotic normalization constant of the bound state. We are presently testing the precision and utility of these relations on simple nuclear systems (16O+p, 16O+n, 12C+α).

Exactly-solvable coupled-channel models from supersymmetric quantum mechanics
Two studies have been performed in the framework of supersymmetry transformations applied to coupled systems of radial Schrödinger equations, in collaboration with B. Samsonov and A. Pupasov (Tomsk, Russia).
When the different channels are characterized by different threshold energies, we have extended our previous works on the supersymmetric formulation of the Cox potential, which can be obtained by a single transformation of the vanishing potential. This has allowed us to perform a general study of the spectral properties of this potential for an arbitrary number of channels. In particular, we could establish limits on its number of bound states and resonances.
On the other hand, we have started a study of the case where the different channels are characterized by equal thresholds. In particular, we have considered single transformations introducing a coupling between initially decoupled channels. We have shown that, in general, such transformations introduce degenerate bound and virtual states, and we have calculated this degeneracy. We have also established a general expression of the Jost-matrix and scattering-matrix modifications introduced by these transformations, and discussed the conditions to get a non trivial coupling. Finally, we have established first schematic two-channel examples, which show that this approach is promising for the solution of the coupled-channel inverse scattering problem.

3.4
Breakup reactions
Breakup reactions are one of the main tools for the study of exotic nuclei. Breakups on light and heavy targets are expected to provide information on spectroscopic properties of halo nuclei. In addition, Coulomb breakup provides an indirect way of studying astrophysical S factors for radiative-capture reactions. The simplest studies were based on perturbation theory and especially on its first order. However the validity of the first-order approximation may be limited for extended systems such as halo nuclei and its conditions are not always satisfied in existing experiments. In recent years, we have developed more elaborate reaction models: resolution of the semi-classical time-dependent Schrödinger equation, eikonal and dynamical eikonal approximations (DEA).

The traditional eikonal approximation is interesting because of its relative simplicity with respect to other elaborate models. However it suffers from a divergence problem at large impact parameters associated with the treatment of the Coulomb interaction. In collaboration with Y. Suzuki (Niigata University, Japan), we have studied a correction curing this problem. This correction is devised in such a way that at large impact parameters the corrected eikonal results tend to those of first-order perturbation theory and the corresponding cross section thus converges. We have tested this improved eikonal treatment with the more elaborate (but much more time-consuming) dynamical eikonal approximation on the 11Be breakup on 208Pb. Excellent results are found for the dissociation of 11Be at 69 MeV/nucleon. The comparison shows that the Coulomb-corrected eikonal approximation (CCE)

reproduces with a satisfactory accuracy most of the observables. The CCE opens the way to purely quantal treatments of the more complicated breakup of three-body projectiles.

The CCE has been extended to the investigation of the elastic breakup of three-body projectiles at intermediate and high energies. This approximation takes full account of final-state nuclear and Coulomb interactions at all orders. The initial bound states and the final scattering states are calculated in hyperspherical coordinates on a Lagrange mesh following a procedure developed by our group in recent years. Contrary to some simpler approximations, the eikonal approximation allows directly calculating various cross sections and in particular multidifferential cross sections can be obtained. The model has been applied to the breakup of 6He on 208Pb at energies typical of RIKEN and GSI experiments. The 6He halo nucleus is described within a three-body α + n + n model involving effective α + n and n + n interactions. The eikonal phase is obtained from optical potentials between α and n, and the target. The total breakup cross sections exhibit around 0.8 MeV a narrow 2+ resonant peak superimposed over a broad bump corresponding to a 1- resonance. These results suffer from a disagreement with the GSI experimental data at 240 MeV/nucleon where cross sections are much smaller at low relative energies between the fragments. The obtained E1 strength distribution resembles other theoretical results which all disagree with the experiment. The confirmation of this disagreement in an elaborate reaction model reopens the problem of the existence of a 1- low-energy resonance in the 6He continuum and suggests that new experiments should be performed to validate or invalidate the GSI data.

As mentioned above, Coulomb breakup is also used as an indirect technique to infer radiative-capture rates at stellar energies. With this aim, the measurement of the Coulomb breakup of 8B has been performed in various laboratories. We have recently shown that the DEA was an ideal tool to study these reactions at intermediate and high energies. The elastic scattering and dissociation of 8B on both light and heavy targets have recently been measured at RIKEN (Japan) at 73 MeV/nucleon. Using the DEA, we provide a theoretical support to that group to analyze the results of their experiment. Up to now, only the elastic scattering data have been exploited, and the DEA has shown to be in excellent agreement with the experimental data. An article presenting these first results has been submitted to Physical Review C, and the study of the breakup measurements is planned for the coming year.

Objective 4:
We want to study medium-heavy and heavy closed shell nuclei in order to obtain key information to test and improve the predictive power of nuclear models far from stability

	Workpackage 4: **Studies of medium-heavy and heavy closed shell nuclei**	**Partners**
1	Study of the changing shell structure in neutron rich nuclei near N=20 and N=28	K.U.Leuven – U.L.B. – U.Gent – GANIL - CSNSM
2	The influence of exotic neutron-to-proton ratios on the shell structure and the onset of collectivity in the neutron-rich Z=28 region.	K.U.Leuven – U.L.B. - U.Gent – CSNSM – Köln – GANIL
3.	Intruder states in the Pb region and the microscopic origin of collectivity	K.U.Leuven – U.L.B. – U.Gent – GANIL – Köln –

		CSNSM – GSI
4	Proof the presence of spin-alignment in relativistic U-fission at the FRS-GSI. Investigate the changing shell structure near the doubly-magic neutron-rich ^{132}Sn via moments measurements.	KU Leuven – Köln – GSI – CSNSM

4.1
Experiment
In the N=20 region, we have been investigating the ground state spins and magnetic moments of the neutron-rich Mg isotopes (Z=12) up to N=21 at the COLLAPS beam line at ISOLDE-CERN. The results from these studies, including spin assignments and a discussion of the nuclear wave functions in the shell model, have now been published (Kowalska et al., PRC77, 2008). It is shown that the ground state magnetic moments of 27,29Mg are well reproduced using the recently improved USDA and USDB interactions, although the agreement is best with the previous USD interaction.
In 2008 we have performed a measurement of the ground state spin and magnetic moment of 21Mg (N=9), at the neutron-deficient side of the valley of stability, using again a combination of the hyperfine structure and β-NMR methods (paper in preparation). This research will continue in 2009, with measurements of the changes in mean square charge radii between N=8 and N=20, to get a direct proof of the static deformation change in these isotopes, expected to set in at N=19.

The Al isotopes (Z=13), also in the N=20 region, are produced better using a fragmentation reaction at GANIL. With the reaction-induced spin-polarization we can perform β̃NMR or β-NQR measurements for determining nuclear g-factors and quadrupole moments of exotic nuclei. The results from an earlier g-factor measurement on 34Al have been published in 2008 (P. Himpe et al., PLB 2008). From a comparison of the measured g-factor to shell model calculations using different interactions in the sdpf model space (with different truncation) it was concluded that a significant amount (~ 50%) of intruder configurations mix into the 34Al ground state. In 2008, we have measured in collaboration with our GANIL partners, the quadrupole moments of the 31,33Al isotopes, revealing a normal ground state structure for 31Al (paper submitted, M. De Rydt et al., PLB 2009). For the 33Al ground state, a significant increase in the deformation is observed. This measurement will be repeated with higher precision in 2009, in order to derive quantitative information about the amount of mixing with intruder configurations in the ground state of this N=20 isotope. These were the first □-NQR measurements which have been performed at GANIL, using a dedicated set-up that has been developed at Leuven and locally installed with the help of the GANIL team.

The odd-Cl ground states (Z=17) from N=20 to N=28 are predicted to have a changing proton ground state structure when filling the N=28 shell, with an inversion between πs1/2 and πd3/2 configurations around 41Cl. In 2008 we have performed several β-NMR measurements on the ground states of 41,42,43Cl, however without having observed a significant resonance effect (within 0.5%). The non-observation of resonances for 41Cl and 43Cl is a strong indication for their ground state to have a spin ½+, dominated by the proton πs1/2 hole configuration. Indeed, for isotopes with the last nucleon in a spherical s1/2 orbital, the polarization is expected to be very small. These experiments will be repeated in 2009 with a higher statistical accuracy (beam time accepted).

With the same motivation as for the Cl studies, a proposal to study the ground state properties of neutron-rich K isotopes (Z=19) around and beyond N=28 has been

accepted by the CERN INTC in februari 2009. These isotopes are ideal to be investigated by collinear laser spectroscopy, using the new ISCOOL cooler/buncher which has been recently installed at ISOLDE-CERN. With this tool, we can improve our detection sensitivity by a factor of 1000 and thus extend the measurements far beyond N=28.

Theory
Within the context of the changing shell structure for neutron-rich light nuclei (N=20), jointly with a large group of experimentalists, and with the theoretical nuclear physics group of the Universidad Autonoma de Madrid (T.Rodriguez, L.Egido,), we have concentrated on the E0 decay of the first excited 0+2 state and studied the ρ2 value connecting to the ground state in 30Mg. The observed small value of 5.7(14) .10-3 indicates very small mixing, pointing towards coexisting configurations with different deformation. Besides beyond-mean field studies of the Madrid group, the results have been interpreted within a two-state mixing model also. These results have been submitted for publication in Phys.Rev.Letters, in 2008.

The N=20 nuclei, jointly with the N=28 nuclei, which are very neutron rich, form part of a review paper that is written jointly with J.L. Wood (Department of Physics, Georgia Technology, Atlanta) for Reviews of Modern Physics. We point out the competing of the monopole energy cost to create neutron 2p-2h excitations, on one hand, and the correlation energy gain, on the other hand, as a unifying theme to describe low-lying intruder configurations and ‘islands of inversion’. This work is in progress.

4.2
Laser spectroscopy
We have performed in-source and collinear laser spectroscopy measurements on Cu isotopes, both on the neutron-rich and neutron-deficient side of the valley of stability at ISOLDE.
In 2008 the ISCOOL cooler/buncher was used for the first time to improve the sensitivity for collinear laser spectroscopy measurements with more than three orders of magnitude. Combining this improved sensitivity with a coarse measurement of the hyperfine parameter for the exotic Cu isotopes using in-source spectroscopy, allowed to perform precision measurements up to ^{75}Cu, and to measure unambiguously the ground state spins of ^{73}Cu and ^{75}Cu. This revealed the inversion of the $\pi p_{3/2}$ and $\pi f_{5/2}$ single particle levels when the $\nu g_{9/2}$ orbital is half filled, leading to a single particle dominated 5/2- ground state for ^{75}Cu. This measurement marks confirms the expected crossing of the 3/2- and 5/2- for the odd mass cupper isotopes when moving towards N=50. The results make the prediction of the structure of 79Cu (one proton coupled to the doubly magic shell model nucleus 78Ni) much more reliable. This confirmation furthermore will guide the implementation of specific aspects of the residual interactions used in this region of the nuclear chart. We have been able to establish as well the ground state spin of ^{72}Cu as well and we could assign a negative parity based on the measured magnetic moment value. This value was suggested from beta decay work from the IAP network (K.U.Leuven, GANIL) and is now firmly established. From the measured quadrupole moments from A=61 (N=32) up to A=75 (N=46), we observed a clear reduction in the ground state deformation when approaching the N=40 semi-magic nucleon number as well as a strong increase in the core polarization of the 3/2- ground state beyond N=40. These measurements are currently being compared with the results from Coulomb excitation measurements on the odd-mass Cu isotopes performed by this IAP network at ISOLDE (published in 2008) and should allow to disentangle the core polarization in the ground state and the low-lying excited states in these nuclei. The

data are being analysed, first papers are in preparation and extended model calculations are underway.

Collinear laser spectroscopy measurements in combination with a bunched Ga beams have been performed as well in 2008. Information on ground state spins and moments of Ga isotopes from A=67 up to A=79 have been obtained. The data are being analysed. Again these data can nicely be combined with the Coulomb excitation data that were obtained on 73Ga at ISOLDE. The fact that the ground state spin of 73Ga is now deduced to be ½- combined with recent deep-inelastic reaction data from Argonne National Laboratory seem to suggest that the ground state of 73Ga is an unresolved doublet of a $1/2^-$ ground state and an excited state with spin/parity $3/2^-$ at an excitation energy < 2 keV. As Coulomb excitation is expected from the g.s (the $3/2^-$ state's half life is expected to be too short to survive the delay time of the ISOLDE target ion source system), but de-excitation probably happens through the $3/2^-$ state, one hopes to extract relevant information from the Coulex data. This specific analysis is underway.

Coulomb excitation

As mentioned above the coulomb excitation (Coulex) results from the neutron-rich cupper isotopes has been published.

In order to understand the structure of the nuclei in f7/2 proton shell, coulomb excitation experiments were planned in the neutron-rich Fe isotopes (Z=26). Previous data from beta decay and deep-inelastic reactions indicate a swift onset of collecitivity in these nuclei when moving away from Z=28 and towards N=40 and beyond. Iron beams are not available at ISOLDE and a new production scheme had to be developed. This scheme consists of the production of intense beams of manganese, beta decay of the manganese to iron, capturing the recoiling iron ions in the Penning trap or the EBIS and post-accelerate to 3 MeV/u. First successful tests have been performed and beams of 61Fe have been produced. The Coulomb excitation of 61Mn and 61Fe was studied.

An experiment to finalize the Coulex measurement on the different isomers of 70Cu was performed in 2008. Due to technical reasons only limited statistics could be gathered. The analysis is ongoing.

Decay studies

Making use of element-selective resonant laser ionization in a buffer gas cell combined with mass separation at the Leuven Isotope Separator On Line (LISOL) facility (Louvain-La-Neuve, Belgium), purified beams of short-lived neutron-rich 65-67Fe isotopes were produced. The isotopes were produced in a proton-induced fission reaction on 238U and yields after mass separation were typically one ion per second. Their decay to 65-67Co was studied using a newly developed detection station, which is digitally read out by XIA-DGF4C modules and which consists out of segmented germanium detectors of the MINIBALL type.

In order to determine the 65-67Co structures, different measurements are carried out on the respective masses. Data are recorded with the lasers switched off and with the lasers tuned to the iron and cobalt resonances. By comparing those data, the γ lines following the 65-67Fe β decay can be identified. Using β–γ–γ coincidences, the 65-67Fe decay schemes are obtained.

In the 67Fe as well as in the 67Co decay, an isomeric transition is observed at 492 keV in the singles γ-ray spectrum, but not in the β-gated γ-ray spectrum. Because of the absence of γ coincidences, the 492-keV transition could not be unambiguously placed a priori in the A=67 decay chain. Correlations with the 492-keV line in longer time ranges up in the order of seconds with β, γ, and β-coincident γ events were required. This has led to a newly developed correlation technique aimed for

applications at ISOL facilities. The formalism, limitations and possibilities of the technique are now published. As today's nuclear-structure studies are mainly aimed at regions far from the line of stability, where the typical β-decay half-lives are in the order of seconds or even smaller, the correlation technique can extensively be exploited to investigate their respective ground and isomeric states.
Thanks to the availability of weak, yet pure beams in low-background conditions at the LISOL facility, correlations between single γ and γ-coincident γ events were unambiguously established in the 67Fe β decay. They fully characterized an isomeric state in 67Co (Z=27, N=40) residing at an unexpected low excitation energy of 492 keV (T1/2=0.50(3) s), which is interpreted as a 1-particle-2-hole (1p-2h) proton intruder state. The construction of the β-decay schemes of 65,67Fe is discussed and under publication. The established 65Co level scheme provides strong indications that the 1p-2h proton intruder state sets in at an excitation energy of 1095 keV, where it coexists with levels arising from a f7/2 proton hole coupled to the 66Ni core. In 66Co, a proton intruder state is observed at merely 176 keV above the ground state.
While 68Ni (Z=28, N=40) still exhibits double-magic properties, the stabilizing effect of the N=40 subshell closure drastically weakens in the cobalt isotopes with only one proton particle less, where the intruder state goes to a minimum excitation energy at N=40 (492 keV). Such an abrupt effect adjacent to a nucleus with double-magic properties is unique. Even in the N=49 isotones counterpart, the stabilizing effect of the Z=40 subshell gap is observed. The intruder configuration is at a minimal excitation energy at 34Se, mid-shell between Z=28 and Z=40 and goes to a maximum again towards 40Zr, consistent with a sub-shell closure at Z=40.
The observation of a proton intruder state in 67Co provides a strong indication that the 0+ proton π(2p-2h) intruder state in 68Ni resides at only 2511 keV, which is compared with the 0+ neutron ν(2p-2h) intruder states in the 90Zr (Z=40, N=50) valence counterpart. The unperturbed shell gaps and pairing energies of both nuclei were determined from measured one- and two-nucleon separation energies following the standard intruder state prescriptions. On this basis, the excitation energies of the suggested neutron ν(2p-2h) and proton π(2p-2h) intruder states revealed information on the strength of proton-neutron residual interactions and, hence, indirectly also on the number of valence nucleons involved. The N=40 and Z=40 subshell gaps in the respective nuclei were found to be not completely rigid. However, this effect is much more pronounced in 68Ni where the proton-neutron interaction strength amounts to 3.5(10) MeV compared to ~500 keV in 90Zr, which is attributed to the strong neutron pair scattering across N=40.
Below Z=28, it is qualitatively understood that the N=40 gap is further weakened under the influence of strong proton-neutron residual interactions. As a result, more pair scattered valence neutrons become available that bring the proton intruder state to lower excitation energies, which is consistent with the observed onset of deformation at N~40 below Z=28. From the low intruder excitation energy in 67Co (492 keV) and the onset of collectivity beyond N=40 in the nickel and copper isotopes, one can expect that the intruder state becomes the ground state in the cobalt and iron isotopes beyond N=40, i.e., a so-called “Island of inversion”. Furthermore, the 65-67Co level schemes offer a well-suited testing ground for adjusting the effective interactions in this region. As such, it may become possible to describe quantitatively nuclei in the region around Z=28 and N=40 and to make predictions toward 78Ni and the possibility of the suggested “'Island of inversion"' in the heavier cobalt and iron isotopes.

Transfer reactions

In 2007 the newly built transfer reaction set-up was tested for the first time in ISOLDE by performing a (d,p) reaction with post-accelerated 30Mg beam, aiming to get a better understanding of the “Island of inversion”. Beside a new scattering chamber

also a series of new particle detectors was used for this experiment together with the MINIBALL γ-detection array. For the 2008 campaign the set-up was modified by adding a delta E-E telescope in the backward barrel (compared to only a delta E-E telescope in the forward direction in 2007) to allow for particle identification. The 2008 experiment was focused on the two-neutron transfer reaction on 30Mg(t,p) to populated 0+ states in 32Mg, especially the spherical 0+ state. For this purpose a radioactive 3H target (implanted in a Ti foil) was used. The experiment was very successful. Beside this also the 30Mg(d,p) reaction was remeasured and a test with a stable 86Kr beam was performed. The datasets are currently under analysis by TU Munchen (30Mg) and KU Leuven (86Kr).
The plans for 2009 are to extend the set-up even more by adding a circular particle detector in the forward direction which will allow us to create a near 4π particle detection coverage. Also a slow coincidence technique will be built which will open the possibility to investigate microsecond isomeric levels populated in the transfer reactions. This set-up will then be used to perform the approved 78Zn(d,p)79Zn and 66Ni(d,p)67Ni reactions which aim at structure studies in the region around 68Ni and 78Ni

4.3
Po laser spectroscopy: status of the analysis
To further the understanding of the effect of shape coexistence in the vicinity of the magic shell closure at Z=82 (lead) but towards the neutron mid-shell (N=104), we are currently investigating the neutron-deficient polonium isotopes 193-204Po. The data acquired in the Summer of 2007 has been thoroughly analysed and the laser spectroscopy resonance curves have been extracted for the 10 isotopes and 4 isomers we investigated so far.
Due to the convolution of the laser profile to the natural shape of the resonance, the fitting procedure is very challenging. We have nonetheless been able to extract the hyperfine parameters and isotope shifts of many of the isotopes. From the overlap of our data set with the earlier study of the more stable isotopes, we could attempt to characterise the atomic properties of the resonance we are investigating. The comparison of this investigation to the atomic large scale calculations was rather unsatisfying and the restudy of the longer-lived isotopes proved to be necessary. An addendum to the experimental proposal was presented at CERN before the INTC in that sense in 2008 and the board of research of CERN eventually allocated 8 days of beam in order to study 10 more isotopes and 4 more isomers. This experiment shall be carried out in 2009.

Electron-capture delayed fission
In June 2008, a successful experiment was performed at the ISOLDE, in which the ECDF of 180Tl was searched for and studied in detail. The ECDF is a very rare nuclear decay (so far only 10 cases are known in the uranium region), in which a parent (Z,A) nucleus first undergoes electron capture decay, populating excited states in the daughter (Z-1,A) nucleus, which then may fission with a certain probability. Such EC-delayed fission is of special interest because it allows to study the fission properties (e.g. decay probability, fission barrier height, mass/charge distribution, total kinetic energy, gamma and neutron multiplicities) of very exotic daughter nuclei, possessing a very low (in practice, un-measurable) spontaneous fission branch.
The uniqueness of ISOLDE for such studies is twofold. First of all, a combination of RILIS&ISOLDE provided a very pure and intense (~150 ions/μC) beam of 180Tl, this is unique worldwide. Secondly, a wind-mill system combined with an efficient and versatile detection system allowed us to measure all possible decay modes of 180Tl and its daughter products, such as α decay, fission, conversion electron emission and gamma decays.

In the experiment, a pure 180Tl beam from RILIS&ISOLDE was implanted (through a hole in an annular Si detector) in a thin carbon foil of 20 μg/cm2 thickness. Twelve such foils were installed on the wheel of the wind-mill system. A second Si detector was installed behind the foil, in such a way that both singles α and fission decays and double-fold fission fragments coincidences could be measured. Gamma rays were detected in a segmented MINIBALL Ge cluster that was installed behind the second Si detector.
The measurements have been performed in the usual 'implantation-decay' mode. During the run, approximately 107 decays of 180Tl were observed, including more than 1300 singles ECDF decays.
A completely unexpected result of the experiment was the observation of asymmetric energy (thus, asymmetric mass distribution) of the fission fragments from 180Hg, being the daughter of 180Tl after an EC decay. Apart from this, a new and precise ECDF branching ratio was deduced for 180Tl, which is by ~100 times larger than the previously reported value. The data analysis is presently in progress, including a collaboration with the theoretical groups from Los Alamos (USA) and JAEA(Japan), working in the field of fission.
The data from the GSI experiment on the neutron-deficient At isotopes where a strong ECDF branch was discovered, were fully analysed and publications are in progress. A new experiment took place at the GSI SHIP velocity filter to study the decay properties of other neutron-deficient nuclei around Z=82. The data are under analysis. New beam time for further experiments at GSI to study 186At and 188,186Bi isotopes was approved and should be scheduled in 2009. Beam time to study the fission process in this region using heavy ion fusion evaporation reactions has been approved at JAEA (Japan) and beam time will be scheduled this year.

Coulomb excitation of the neutron-deficient $^{188-182}$Hg isotopes
Since a clear shape dissimilarity in the ground state of light odd-mass mercury isotopes was observed by means of isotope shift measurements, shape coexistence in this mass region has been an intensively studied phenomenon by means of in-beam and decay spectroscopy. For light even-mass mercury isotopes, it has been advocated that a prolate band at low excitation energy is coexisting with an oblate ground state band. The prolate states are associated with the excitation of four protons across the major Z=82 shell gap into the h9/2 and f7/2 orbitals (π(4 particles – 6 holes) configuration) while oblate states are associated with the π(0 particles – 2 holes) configuration. There now exists a large body of evidence supporting the coexistence of different shapes at low excitation energies in mercury isotopes.
Coulomb excitation at safe energies serves as a vigorous technique to investigate the magnitude of transitions between low-lying states, revealing information on the mixing of the different bands. Pure beams of 182,184,186,188Hg were delivered to a stable Cd target (112Cd or 114Cd) placed in the middle of the MINIBALL gamma spectrometer to induce Coulomb excitation. The obtained beam intensities were sufficient for the detection of low-lying, low-spin states. Observed de-excitation rates enable the transitional quadrupole matrix elements connecting different states to be extracted. Also the sign of the diagonal matrix element of the first excited 2+ state, containing the information about the nuclear quadrupole deformation, will experimentally be determined. In addition to the decay of the first 2+ state, transitions from the second 2+ state and from the first 4+ state have been observed during the experiment.
A proposal to study Coulomb excitation in the neutron deficient polonium isotopes has been worked out and accepted by the INTC. The beam time is scheduled for 2009.

Theory

In the Pb neutron-deficient nuclei ($186 \leq A \leq 196$), we have made use of a symmetry truncation to the shell model i.e. the Interacting Boson Model (IBM) to understand both the presence of collective band structure and the systematics of these bands as a function of mass number. We have calculated extensively energy spectra and B(E2) values for 188-196Pb. These results shed light on the possible classification of levels in specific bands. Furthermore, quadrupole deformations have been extracted for these Pb nuclei and the mixing between the different families i.e. 0p-0h, 2p-2h, and 4p-4h , is studied in detail. We are now able to compare the experimental with the theoretical level systematics. These results have been published in Phys.Rev.C.

As already discussed in the former report (2007), the general study of the criticality when covering the full phase diagram including various possible coexisting shapes has been finished and results are in print in Nuclear Physics A. In this second paper, we have found that next to the possibility of describing SU(3)-SU(3) and O(6)-O(6) mixing, it is possible to obtain prolate – oblate shape coexisting situations, depending on the precise structure of the quadrupole operator used in the IBM.

In the report of last year, we have reported on a new approach that should allow to describe collective vibrational, rotational, gamma-soft and even shape coexisting phases. An algebraic approach was developed. The results on the mathematical structure have been published in the literature (see publication list of the report 2007, and in the present report, publications 2008). This research fits in an extensive collaboration with Prof. D.Rowe (Dept. of Physics, University of Toronto, Canada) and collaborators that is growing in scope (Prof. M.Caprio from the Physics Dept. of the University of Notre-Dame has become a partner). During last year, a number of most interesting applications have been obtained. Truncating the potential energy up to quartic terms in the quadrupole deformation variables, it was possible to incorporate the vibrational, gamma-independent rotational and axially deformed rotational structures. These important limits, which are very important, have been analyzed in detail and have been confronted with well-established approximation schemes i.e. the harmonic oscillator, the Wilets-Jean, and the rotation-vibration model (RVM), respectively. We moreover study the possible three transition regions between these three limiting cases for energy spectra, B(E2) values and also quadrupole moments. With these encouraging results, we can definitely start to study more realistic nuclei in transitional regions as well as handle various shape-coexisting systems. We stress again that these results are obtained within the recently presented Cartan-Weyl framework in order to calculate the SU(1,1) x SO(5) embedded quadrupole collective observables. The most recent results are in print for Phys.Rev.C.

In the course of 2008, intensive work has been carried out to understand the way shape coexisting configurations, clearly observed in the Pb and Hg nuclei, propagate when moving away from the Z=82 closed shell. The Pt nuclei form a particular important series of isotopes in this respect. With Prof. J.E. Garcia –Ramos (Univ.Huelva and Sevilla), we have carried out and extensive comparison between calculation explictely incorporating intruder configurations (IBM-CM) with calculations, carried out recently by McCutchan et al., in which intruder configurations are not taken into account (CQF). In order to resolve this enigmatic situation, an extensive comparison of these two approaches is carried out. Our first results were unexpected, showing that if one only considers, energies and E2 properties for a subgroup of levels (below $E_x \leq 1.5$ MeV), the results are indeed very similar not allowing to discriminate between the two approaches. These results are now in print for Nucl.Phys.A. Studying many more observables (such as g-factors, relative B(E2) values, α-decay hindrance factors, isotopic shifts, ρ2(E0) values, properties in adjacent odd-mass Pt and Au nuclei) should allow to discover differences in the two descriptions and obtain a deeper understanding of what

precisely happens with the obvious shape coexisting structures, when moving away from the Z=82 closed shell. We expect to invest a large amount of energy in this important research topic in 2009. The input from new experiments in the Pb region (such as Coulomb excitation and transfer reactions using unstable nuclei) will be instrumental in that respect too.

Finally, we have continued to apply our beyond mean-field model to the spectroscopy of nuclei in the vicinity of the Z=82 closed shell, to neutron deficient isotopes. These applications are performed in collaboration with experimental groups and are used to interpret and analyse their data.
Let us recall the two steps of our method. The first step is constituted by mean-field calculations with a Skyrme effective interaction and a constraint on the axial quadrupole moment. In a second step, the mean-field wave functions are projected on good angular momentum and particle numbers. Finally, a configuration mixing as a function of the axial quadrupole moment is performed.
In collaboration with the experimental groups of Liverpool and Jyväskylä, we have applied this method to 196Po for which new data have been obtained. The picture that emerges from this calculation is different from the usual interpretation made for this nucleus, where the whole low-energy level scheme is associated with a simple vibrator. Our results indicate the mixing of the vibrational and rotational configurations at low spin, in agreement with the experimental data.
The starting point of our method is an energy density functional, which is adjusted on a few key data and used without changes all over the nuclear chart. The study of nuclei far from stability shows that the usual energy density functionals are not flexible enough and must be completed by new terms, in particular a tensor interaction and time odd terms which appear in the description of odd nuclei. We have started an extensive study of both terms whose first results invalidate results obtained by other groups on the basis of non self consistent calculations. These studies should be completed in 2009.

4.4
The first gamma-spectroscopy results from a g-factor experiment performed at the FRS-GSI within the g-RISING collaboration have been analysed at Leuven and were published in 2008 (R. Lozeva et al., PRC77, NPA 805, 2008). Three new isomers have been observed in the 125,127,129Sn isotopes, completing the isomer systematics approaching the N=82 shell gap. The g-factor of two isomeric states in 126Sn and 127Sn has been analysed at Koln, supporting the tentatively assigned spin and configuration for these states. For the first time, spin-alignment has been observed in relativistic fission reactions, thus opening the way for isomeric moments studies on isotopes otherwise hard to orient (G. Ilie et al., submitted to PRL). All these results will shed light on the evolution of shell structure when approaching the neutron-rich doubly-magic 132Sn.

Objective 5:
We want to study the nuclei along the N=Z line elucidating the neutron-proton pairing interaction, verifying isospin symmetry and studying the weak interaction in the atomic nucleus.

	Workpackage 5: Nuclei along the N=Z line	**Partners**
1	Mass measurements of N=Z nuclei	K.U.Leuven - GSI
2	Theoretical studies along the N=Z line	U.Gent – U.L.B. - GANIL
3	Beta-decay studies along the N=Z line	K.U.Leuven – GSI
4	Improve the efficiency and sensitivity of the	K.U.Leuven – GANIL - GSI

	WITCH set-up	
5.	Optimise the determination of the beta-asymmetry parameter and obtain improved precision	K.U.Leuven – CSNSM
6	Weak interaction studies using the WITCH spectrometer and low-temperature nuclear orientation devices	K.U.Leuven – GANIL - CSNSM

5.1
No activity to be reported

5.2
Mass differences are an often used signature and measure for shell closure. Using the angular-momentum projected Generator Coordinate Method and the Skyrme interaction SLy4, we have analyzed the modification of mass differences due to static deformation and dynamic fluctuations around the mean-field ground state. Looking at the shell closures where the S2q values exhibit discontinuities, static mean-field deformations and dynamical correlations decrease systematically the amplitude of these gaps, and reduce them far from stability. Both effects are not related to a reduction of the spherical shell structure, which is usually invoked, but rather both underline the importance of fluctuations around single mean-field configurations for a high-precision description of nuclear masses. Our systematic calculation shed a new light on the effect that is usually interpreted as due to the quenching of spherical shell gaps.

The study of level densities in which, using a new technique, both angular momentum and parity projected results could be derived were already commented in the 2007 report. These results have been slightly improved and allow to handle very big model spaces, encompassing both the full sd, fp, 1g9/2 and next sd shell-model space. Results for the 55,56,57Fe isotopes have been obtained. One observes a clear pairing phase transition through the angular momentum distribution of the nuclear level density. This research topic to which S.Rombouts, K.Van Houcke and K.Heyde (jointly with J.Dukelsky (Madrid) and Y.Alhassid (Yale University)) have contributed has reached its goals.

5.3
Laser spectroscopy of 57Cu
As mentioned in WP1, we proceeded to measure the hyperfine structure of the neutron-deficient copper isotopes 57Cu and 59Cu by means of in-gas-cell laser spectroscopy at LISOL, in order to extract their magnetic dipole moments; those had previously been measured by nuclear magnetic resonance but confirmation of those measurements was necessary. The two isotopes could be studied systematically to a great extent. The measurement was reproduced many times to guarantee the accuracy of our results and to check the stability of the global measurements system (laser frequency, laser band width, total resonance width, cyclotron beam conditions). The previous, very precise, measurement of the magnetic dipole moment of 59Cu has been confirmed. In the case of 57Cu, our result is in contradiction with the nuclear magnetic resonance measurement. After careful study of our experimental conditions and of the systematic effects associated to our setup, we concluded that our measurement was accurate; on the other hand, the previous measurement suffered from poor statistics and was never reproduced. The results have been compared to different calculations in the frame of the nuclear shell model. It shows that current calculations based on a good 40Ca core involving the full fp-shell as valence space for the nucleons is sufficient to reproduce the behaviour of the magnetic dipole moment in the neutron-deficient copper isotopes. The use, however, of a 56Ni core, ie one proton number below 57Cu, using the fp-shells as well as the

g9/2 shell, overestimates greatly the magnetic dipole moments, despite its ability to reproduce very well the magnetic dipole moments of the neutron-rich copper isotopes beyond 69Cu. This shows how sensitive the nuclear structure is in this region of the nuclear chart and while 56Ni has Z and N magic numbers, its magic character cannot be taken for granted while discussing the surrounding nuclei. Following in the footsteps of this great result, exotic nuclei even further from stability are being investigated as well as other elements, like the neutron-deficient silver isotopes, that can be studied in this fashion only at LISOL.

Beta decay studies along the N=Z line
With the new shadow gas cell laser ion source, developed for LISOL (see WP 1), new experiments will become feasible because of the higher degree of selectivity attainable. A preliminary study on the possibilities using the available heavy ion beams at LLN, the physics interest in the nuclear structure refractory type elements (uniqueness versus other facilities) was launched. New experiments are planned in 2009.

On the gamma detection side, a detector specialist was hired and the detector lab at K.U.Leuven was upgraded. Initial training in segmented Miniball type detectors was started. This should result in the operation of the 12-fold triple detector for experiments in 2009.

5.4
In the past year several technical improvements of the WITCH set-up have been performed or are still ongoing:
- the vacuum system was upgraded: all non-UHV compatible materials were removed and a large amount of non-evaporative getter material was installed. This has significantly increased the pumping speed. A vacuum in the 10-10 mbar region is now feasible, i.e. an improvement of more than an order of magnitude.
- a compact linear RFQ-trap to transform the beam from our stable beam ion source into bunches of several pA intensity was developed and successfully tested.
- a magnetic shield to limit the stray field of the WITCH magnet at the neighboring REX-ISOLDE beam line was designed and is now being constructed. Installation is foreseen for April 2009. With this shield and the RFQ-trap in place the amount of time available for testing and optimizing the WITCH setup with stable beams will be enhanced significantly.

5.5
The Geant 4 Monte Carlo simulation code that was developed for beta-asymmetry parameter measurements was further optimized with respect to the effects of scattering and of the magnetic field. The code was used in the analysis of experiments with 60Co and 114In. It also helped to identify and quantify different types of systematic effects. Two papers, one on the operation of Si PIN diodes for particle detection at 10K and in magnetic fields up to 11 T, and a second one on the Geant simulation code that was developed, were submitted to Nucl. Instrum. & Meth.
Last year already a precision of 2% on the asymmetry parameter for 60Co was obtained, i.e. as good as the best result available in literature to date. In the mean time the amount of statistics in the Geant 4 Monte Carlo simulations that are used in the data analysis was improved by a factor of 10. These results are at present being analyzed. A new measurement was in the mean time performed as well, using 67Cu at ISOLDE-CERN. Also these data are still being analyzed.

5.6
Two beta-asymmetry parameter measurements using low-temperature nuclear orientation were performed with 60Co and 114In. For 60Co a precision of 1.6% was

achieved, while the measurement with 114In has yielded a precision of 1.4%. These are the most accurate results for the beta-asymmetry parameter in nuclear transitions ever achieved, and they provide new information on a possible tensor contribution to the weak interaction. A paper on 114In was submitted to Phys. Rev. Lett., while a paper on the measurement with 60Co is in preparation.
Finally, we have analyzed - in collaboration with I.S. Towner (Texas A&M Univ., USA) – the corrected Ft-values for the T = 1/2 mirror transitions up to 43Ti, including the radiative and nuclear structure related corrections, similar to the superallowed 0+□ 0+ transitions. This was published in Phys. Rev. C. These Ft-values are necessary to interpret ongoing and future correlation measurements in the decay of the mirror nuclei to search for physics beyond the standard model.

Objective 6:
We want to study neutron-induced reactions on rare isotopes of interest for astrophysical and nuclear waste transmutation processes.

	Workpackage 6: **Structure and reactivity of rare actinides**	**Partners**
1	Structure and reactivity of rare actinides, experimental determination of the Cm(n,f) cross section	SCK•CEN, U.Gent, U.L.B., CSNSM

6.1
Experiment
The thermal neutron induced fission cross section of a series of Cm isotopes needs to be determined at the BR1 reactor at SCK•CEN. For this purpose a dedicated experimental setup was installed at one of the irradiation channels of BR1 in 2007, including neutron beam optimisation and characterisation. The acquisition system was developed by U.Gent and modified to the specific requirements of the experiments at BR1.
A first series of measurements was performed in order to determine the thermal neutron induced 247Cm(n,f) cross section. For this purpose a highly enriched 247Cm target was mounted in the ionisation chamber. The measurement results showed a degraded fission spectrum, indicating that the 247Cm sample is crystallised and is therefore not suited anymore for an accurate cross section measurement. Another (anticipated) difficulty was the alpha pile-up due to spontaneous alpha-decay (mainly from 244Cm impurities). The alpha count rate recorded with the ionisation chamber was about 5 x 10^5 s-1, which was at the operational limit of the detector.
A second series of measurements focussed on the 245Cm(n,f) reaction. As the alpha count rate due to spontaneous decay was expected to be about five times higher than with the 247Cm sample, a faster detection system needed to be developed. This new system consists of PIPS detectors mounted in a vacuum chamber. A complete measurement campaign was executed, including background measurements to correct for spontaneous fission and for epithermal neutron induced fission. A preliminary thermal neutron induced 245Cm(n,f) cross section value has been obtained. Possibilities to improve the accuracy on the results are currently being investigated (better target characterisation, experimental determination of the Westcott factor) before the final result will be communicated.

Measurements of the 245Cm(n,f) cross section have been started at GELINA neutron time of flight facility of the Institute for Reference Materials and Measurements (IRMM) in Geel. A vacuum chamber with two 3000 mm2 large silicon surface barrier detectors for the detection of the fission fragments and the 10B(n,α) particles (for the determination of the neutron flux) has been mounted in the neutron beam at a 9 meter long flight path. A calibration experiment based on the well known 235U(n,f)

cross section has been performed to validate the experimental setup and the data reduction programme. Then a first measurement of the 245Cm(n,f) cross section has been done in the sub-thermal and thermal neutron energy region, GELINA being operated at a repetition frequency of 50 Hz. Consequently measurements have been started in the 245Cm(n,f) resonance region, GELINA being operated at a repetition frequency of 800 Hz. The data taking is still ongoing.

Theory
The rotational structure of 255Lr has been investigated in collaboration with a group of Jyväskylä who has performed in-beam gamma-ray experiment. This nucleus is the heaviest element for which there is rich information on the low energy spectrum. Our calculation has permitted to assign a configuration to the rotational band which has been detected up to a spin around 20 hbar.

Objective 7:
We want to investigate the feasibility of using the high power proton beam that will become available in the MYRRHA accelerator driven system for Belgian fundamental nuclear-physics research.

	Workpackage 7: **Physics with intense proton beams**	**Partners**
1	Feasibility/exploratory study of an irradiation station with 5/2.5 mA protons at 350/600 MeV, opportunities for Belgian fundamental research on radioactive nuclei on the long term	SCK•CEN, K.U.Leuven, U.Gent, U.L.B. - Köln

7.1
The development of the MYRRHA accelerator driven system is one of the main activities at SCK•CEN. In work package 7 we want to investigate the feasibility of using the high power proton beam that will become available in the MYRRHA accelerator driven system for fundamental research.

In order to have a global overview of existing large-scale proton facilities and research programmes, the workshop "Nuclear Physics Research at the MYRRHA accelerator" was organised on 7-8 April 2008 at the SCK•CEN, in combination with the annual BriX network meeting. About 50 people participated to the workshop.

In the first session, an overview of the most important large scale proton facilities was presented. This session ended with a presentation of the MYRRHA facility, with special emphasis on the accelerator and the spallation target. The second session started with a presentation on the possibility of an ISOL (Isotope Separator OnLine) facility at MYRRHA and the beams that might become available. The rest of this session focussed on research programmes at existing facilities. The workshop was concluded with a round-up and a round-table discussion.

In the round-table discussion it was concluded that the installation of an ISOL system at the MYRRHA accelerator, called ISOL@MYRRHA, would offer unique research opportunities that are complementary with existing radioactive ion beam facilities. A first work plan towards ISOL@MYRRHA is established. A report containing the workshop summary, technical feasibility, cost estimate and operational model of ISOL@MYRRHA is in preparation.

The presentations of the workshop are listed below and can be found on the BriX web site (http://iks32.fys.kuleuven.be/iap_wiki/index.php/Main_Page):

Existing large scale proton facilities & MYRRHA

Radioactive beams with a high intensity proton driver: The Eurisol project
Y. Blumenfeld (CNRS, Orsay)
Neutrons for Science (NFS) at SPIRAL2
D. Ridikas (CEA, Saclay)
Current Status & Future Plans for the TRIUMF ISAC Radioactive Beam Facility
M. Dombsky (Triumf)
From ISOLDE to MYRRHA
J. Lettry (ISOLDE)
MYRRHA
H. Aït Abderrahim (SCK•CEN)
MYRRHA in a European context
A. Mueller (CNRS, Orsay)

Users and scientific programs at existing facilities

Applications of intense low-energy ISOL beams
U. Köster (ILL)
Simulations and Measurements for projectile and fission fragments
M. Ricciardi (GSI)
Radioactive Ion Beam Production by Neutron-Induced Fission in Actinide Targets at EURISOL Multi-MW Converter Target
Y. Kadi (CERN)
Challenges for light nuclei
K. Riisager (CERN)
Depth contolled Li-8 beta-NMRand Physics at Interfaces
Z. Salman (Oxford)
Emission channeling from short-lived isotopes
U.Wahl (Univ. Lisbon)
Production of long lived exotic radionucleides for nuclear physics experiments
D. Schumann (PSI)
Precision measurements for CVC tests
B. Blank (Univ. Bordeaux)
Fundamental interaction studies using beta decay of radioactive nuclei
N. Severijns (KUL)
TRIµP: atomic traps for the study of fundamental interactions and symmetries
H. Wilschut (KVI)
High-precision experiments using radioactive ions, lasers and/or storage devices
J. Kluge (GSI)

Perspectives for MYRRHA

Round-up and discussion
P. Van Duppen (KUL)

2. Network organisation and operation

The network involves experimental nuclear physics groups from the universities of Leuven (K.U.Leuven) and Gent (U.Gent) and theoretical groups from the universities of Brussels (U.L.B.) together with the European partners GANIL (France), GSI (Germany), IKP – U.Köln (Köln) and CSNSM (Orsay). An intense collaboration with ISOLDE-CERN (Switzerland) exists as well. During the numerous experimental campaigns at ISOLDE-CERN, GANIL, GSI and at the Orsay tandem accelerator contacts between the different members of the BriX network are established.

Apart from the research performed within the groups, an intense networking activity is developed that results in a number of joint publications (see list of "co-publications"). Partners of the network are also involved in the organization of different workshops and schools.

a. Meetings and worskhops

Apart from the seminars and specific discussion meetings between the different partners, a few workshops and schools were organized (partly) in the framework of the IAP network. These workshops and schools are listed below:

"Nuclear Physics Research at the MYRRHA accelerator"
April 7-8 , 2008, SCK•CEN, Mol, Belgium

"IAP - BriX day"
April 9, 2008, SCK•CEN, Mol, Belgium

"Euroschool on Exotic Beams"
September 1 – 6, 2008, Piaski, Poland

Joint LASER – TRAPSPEC workshop
September 28 – October 1, 2008, La Londe des Maures, France

"ISOLDE Workshop and Users Meeting"
November 17 – 19, 2008, CERN, Geneva, Switzerland

Miniball workshop and users meeting
December 8 – 10, 2008, Munchen, Germany

b. Exchange of data, material and personnel

Exchanges of personnel within the IAP

- S. De Baerdemacker: 1.1.2008 – 31.8.2008: Long stay at the Physics Department of the University of Toronto (group of Prof. D.Rowe) within the IAP. From 1.9.2008, 3 year postdoctoral position at the FWO-Vlaanderen., extending his long stay up to 30.9.2009.
- V.Hellemans: 1.1.2008 – 31.12.2008: Postdoctoral position at the ULB (group of Prof. P.-H. Heenen) within the IAP
- K.Van Houcke: 1.10.2007: 3 year postdoctoral position at the FWO-Vlaanderen, with a long stay (1.1.2008 – 31.12.2008) at the Physics Department of the University of Massachusetts, Amherst, USA
- R. Lozeva, post-doc at K.U. Leuven in 2006-2007, obtained a post-doc position at the CSNSM in 2008-2009.
- R. Raabe, post-doc at K.U.Leuven obtained a permanent position at GANIL in 2008

- Teaching: K.Heyde has taught a specialized course on Nuclear Physics in the program ‘Master of Physics’ at the KULeuven.
- Staff from the ULB (S. Goriely and P.H. Heenen) and of U.Gent (K. Heyde) is teaching specialized nuclear physics and astrophysics courses in the ‘Master of physics’ trajectory of “physics on femtometer scale: nuclear physics” at the K.U. Leuven.

Exchange of data and material

Exchange of material between SCK•CEN and U.Gent for workpackage 6. Acquisition system, ionisation chamber and part of the electronics are provided by U.Gent for the measurements at the BR1 reactor.

Exchange of data on the Cu Coulex between K.U.Leuven and CSNSM has been established.

Exchange of data on the Po laser spectroscopy between K.U.Leuven, Mainz and ISOLDE has been established.

Exchange of data on the beta decay of neutron-rich Cu isotopes between K.U.Leuven and GANIL

Exchange of know-how on segmented Ge detectors between U.Köln and K.U.Leuven

Exchange of know-how on the analysis of Coulomb excitation data between K.U.Leuven, U.Köln and CSNSM

3. List of publications

a. List of publications for every partner (excluding the co-publications that involve different institutes from the network)

K.U.Leuven

Acta Physica Polonica B39 (2008) 411-416; *Parity non-conservation observed in nuclear γ decay of ^{180m}Hf;* D. Zakoucky, J.R. Stone, G. Goldring, N.J. Stone , N.Severijns, M. Hass, T. Giles, U. Koester, I.S. Kraev, S. Lakshmi, M.Lindroos, F.Wauters.

Nuclear Instruments & Methods in Physics Research B 266 *(2008)* 681-700; *Off-line studies of the laser ionization of yttrium at the IGISOL facility;* Kessler T., Moore I., Koudriavtsev I., Perajarvi K., Popov A., Ronkanen P., Sonoda T., Tordoff B., Wendt K., Aysto J..

Nuclear Instruments & Methods in Physics Research B 266 *(2008)* 4368-4372; *Characterization of the LISOL laser ion source using spontaneous fission of 252Cf;* Koudriavtsev I., Cocolios T., Gentens J., Ivanov O., Huyse M., Pauwels D., Sawicka M., Sonoda T., Van den Bergh P., Van Duppen P..

Nuclear Instruments & Methods in Physics Research B 266 *(2008)* 4403-4406; *Resonant laser ionization of polonium at RILIS-ISOLDE for the study of ground- and isomer-state properties;* Cocolios T., Marsh B., Fedosseev V., Franchoo S., Huber G., Huyse M., Ionan A., Johnston K., Koster U., Koudriavtsev I., Seliverstov M., Noah E., Stora T., Van Duppen P..

Nuclear Instruments & Methods in Physics Research B 266 *(2008)* 4515-4520; *The WITCH experiment: Acquiring the first recoil ion spectrum;* Kozlov V., Beck M., Coeck S., Delahaye P., Friedag P., Herbane M., Herlert A., Kraev I., Tandecki M., Van Gorp S., Wauters F., Weinheimer C., Wenander F., Zakoucky D., Severijns N. *(Cit: 0)*.

Nuclear Instruments & Methods in Physics Research B 266 *(2008)* 4600-4605; *Decay correlations in the seconds range with laser-ionized, mass-separated beams;* Pauwels D., Ivanov O., Büscher J., Cocolios T., Gentens J., Huyse M., Korgul A., Koudriavtsev I., Raabe R., Sawicka M., Stefanescu I., Van de Walle J., Van den Bergh P., Van Duppen P..

Nuclear Instruments & Methods in Physics Research B 266 *(2008)* 4687-4691; *HIE-ISOLDE;* Lindroos M., Butler P., Huyse M., Riisager K. *(Cit: 1)*.

Nuclear Physics A 803 *(2008)* 30-45; *Study of the elastic scattering of 6He on 208Pb at energies around the Coulomb barrier;* Sanchez-Benitez A., Escrig D., Alvarez M., Andres M., Angulo C., Borge M., Cabrera J., Cherubini F., Demaret P., Espino J., Figuera P., Freer M., Garcia-Ramos J., Gomez-Camacho J., Gulino M., Kakuee O., Martel I., Metelko C., Moro A., Perez-Bernal F., Rahighi J., Rusek K., Smirnov D., Tengblad O., Van Duppen P., Ziman V. *(Cit: 5)*.

Nuclear Physics A 805 (2008) 335-337; *New μs isomers found in the neutron rich Sn isotopes;*
R. Lozeva , G. Neyens, G.S. Simpson and N. Vermeulen, for the g-RISING collaboration.

(Proceedings of the Int. Nuclear Physics Conf. 2007, INPC2007, Tokyo, Japan, June 3-8, 2007)

Physical Review C 77 *(2008)* 034307, 11; *Nuclear ground-state spins and magnetic moments of Mg-27, Mg-29, and Mg-31;* Kowalska M., Yordanov D., Blaum K., Himpe P., Lievens P., Mallion S., Neugart R., Neyens G., Vermeulen N. *(Cit: 1)*.

Physical Review C 77, 064313 (2008); *New sub-μs isomers in ^{125,127,129}Sn and isomer systematics of $^{124–130}$Sn*; R. L. Lozeva, G. S. Simpson, H. Grawe, G. Neyens, L. A. Atanasova, D. L. Balabanski, D. Bazzacco, F. Becker, P. Bednarczyk, G. Benzoni, N. Blasi, A. Blazhev, A. Bracco, C. Brandau, L. C´aceres, F. Camera, S. K. Chamoli, F. C. L. Crespi, J.-M. Daugas, P. Detistov, M. De Rydt, P. Doornenbal, C. Fahlander, E. Farnea, G. Georgiev, J. Gerl, K. A. Gladnishki, M. G´orska, J. Gre˛bosz, M. Hass, R. Hoischen, G. Ilie, M. Ionescu-Bujor, A. Iordachescu, J. Jolie, A. Jungclaus, M. Kmiecik, I. Kojouharov, N. Kurz, S. P. Lakshmi, G. Lo Bianco, S. Mallion, A. Maj, D. Montanari, O. Perru, M. Pf¨utzner, S. Pietri, J. A. Pinston, Zs. Podoly´ak, W. Prokopowicz, D. Rudolph, G. Rusev, T. R. Saitoh, A. Saltarelli, H. Schaffner, R. Schwengner, S. Tashenov, K. Turz´o, J. J. Valiente-Dob´on, N. Vermeulen, J. Walker, E. Werner-Malento, O. Wieland, and H.-J. Wollersheim.

Physical Review C, Nuclear physics 78 *(2008)* 041307(R); *Shape isomerism at N = 40: Discovery of a proton intruder state in 67Co;* Pauwels D., Ivanov O., Bree N., Büscher J., Cocolios T., Gentens J., Huyse M., Korgul A., Koudriavtsev I., Raabe R., Sawicka M., Stefanescu I., Van de Walle J., Van den Bergh P., Van Duppen P., Walters W..

Physical Review C 78 *(2008)* 055501, -; *Ft values of the T=1/2 mirror beta transitions;* Severijns N., Tandecki M., Phalet T., Towner I. *(Cit: 0)*.

Physical Review letters 101 *(2008)* -; *Precision measurement of Li-11 moments: Influence of halo neutrons on the Li-9 core;* Neugart R., Balabanski D., Blaum K., Borremans D., Himpe P., Kowalska M., Lievens P., Mallion S., Neyens G., Vermeulen N., Yordanov D. *(Cit: 0)*.

U.L.B.

European Physical Journal Special Topics 156 (2008) 93-122; *Breakup reaction models for exotic nuclei;* D. Baye.

Few-Body Systems 43 (2008) 45-50; *Microscopic cluster models in nuclear astrophysics;* P. Descouvemont.

Journal of Physics G 35 (2008) 014006, 1-7; *Cluster models in nuclear astrophysics;* P. Descouvemont.

Journal of Physics A 41 (2008) 175209; *Spectral properties of non-conservative multichannel SUSY partners of the zero potential;* A.M. Pupasov, B.F. Samsonov and J-M. Sparenberg.

Journal of Physics: Conf. Ser. 111 (2008) 012009; *Microscopic cluster description of light nuclei;* P. Descouvemont.
(9th International Conference on Clustering Aspects of Nuclear Structure and Dynamics)

Journal of Physics: Conf. Ser. 111 (2008) 012045; *3α description of ^{12}C with microscopic nonlocal potentials;* M. Orabi, Y. Suzuki, H. Matsumura, Y. Fujiwara, D. Baye, P. Descouvemont and M. Theeten.
(9th International Conference on Clustering Aspects of Nuclear Structure and Dynamics)

Journal of Physics: Conf. Ser. 111 (2008) 012046; *Three-cluster models for light nuclei;* M. Theeten, D. Baye, P. Descouvemont, Y. Fujiwara, H. Matsumura, M. Orabi and Y. Suzuki.
(9th International Conference on Clustering Aspects of Nuclear Structure and Dynamics)

Journal Modern Physics E 17 (2008) 2301; *Three and four-body breakup reactions;* D. Baye.

Modern Physics Letters B 22 (2008) 2277; *Exactly-solvable coupled-channel models from supersymmetric quantum mechanics;* J-M. Sparenberg, A.M. Pupasov, B.F. Samsonov and D. Baye.

Nuclear Physics A813 (2008) 252-261; *Microscopic cluster model of ^5H and ^5He (T=3/2);* A. Adahchour, and P. Descouvemont.

Physical Review A 77 (2008) 012724 (14 pages); *Exactly Solvable Coupled-Channel Potential Models of Atom-Atom Magnetic Feshbach Resonances from Supersymmetric Quantum Mechanics;* A. M. Pupasov, B. F. Samsonov and J.-M. Sparenberg.

Physical Review C 78, 015808 (2008) (11 pages); *$^{12}C(\alpha,\gamma)^{16}O$ E2 cross section: R-matrix fits combined with a microscopic cluster model*; M. Dufour and P. Descouvemont.

Physical Review C 78 (2008) 024309, 1-16; *Configuration mixing of angular-momentum and particle-number projected triaxial Hartree-Fock-Bogoliubov states using the Skyrme energy density functional;* M. Bender and P-H. Heenen.

Physical Review C 78 (2008) 054602, 1-10; *Coulomb-corrected eikonal description of the breakup of halo nuclei;* P. Capel, D. Baye, and Y. Suzuki .

Physical Review C78 (2008) 054312, 1-7; *Collectivity-induced quenching of signatures for shell closures;* M. Bender, G. F. Bertsch, and P.-H. Heenen.

Physical Review. C79 (2009) 014319, 1-7; *Nuclear tetrahedral configurations at spin zero;* K. Zberecki, P.-H. Heenen, and P. Magierski .

Physical Review C 79 (2009) 024607, 1-16; *Four-body calculation of ^6He breakup with the Coulomb-corrected eikonal method;* D. Baye, P. Capel, P. Descouvemont, and Y. Suzuki.

Physics Letters B 659 (2008) 160-164; *Local versus nonlocal α α interactions in a 3α description of ^{12}C;* Y. Suzuki, H. Matsumura, M. Orabi, Y. Fujiwara, P. Descouvemont, M. Theeten and D. Baye.

Physics Letters B 659 (2008) 864; *Evidence for core excitation in single-particle states of ^{19}Na;* M.G. Pellegriti, N.L. Achouri, C. Angulo, J.-C. Angelique, E.

Berthoumieux, E. Casarejos, M. Couder, T. Davinson, C. Ghag, A.St. Murphy, N.A. Orr, I. Ray, I.G. Stefan, P. Descouvemont.

Proceedings of the Second International Conference on Frontiers in Nuclear Structure, Astrophysics and Reactions (FINUSTAR), Aghios Nikolaos (Greece) 10-13 September 2007, AIP Conference Proceedings, Volume 1012, p. 165-172
Recent developments in Coulomb breakup calculations; P. Capel.

Proceedings International Nuclear Physics Conference (INPC2007), Tokyo (Japan) 3-8 june 2007, Elsevier, P. 486-488; *Coulomb breakup of ^{8}B within a dynamical eikonal approximation*; G. Goldstein, P. Capel, and D. Baye.

IJMPE 17 (2008) 2165-2170; *Cross sections for nuclear astrophysics;* P. Descouvemont.

U.Gent

Journal of Physics A: Mathematical Physics 41 (2008), 3040239; *The quadrupole collective model from a Cartan-Weyl perspective;* S. De Baerdemacker, K. Heyde and V. Hellemans.

Nuclear Physics News Int., vol.18,4 (2008), 37; K.Heyde
Meeting Reports: The 13th International Conference on Capture Gamma-Ray Spectroscopy and Related Topics – CGS13

Nuclear Physics A (2009), in print; *Criticallity in the configuration-mixed Interacting Boson Model: (II)Q(χ)Q(χ) mixing;* V. Hellemans, P. Van Isacker, S. De Baerdemacker and K. Heyde.

Nuclear Physics A (2009), in print; *The Pt isotopes: comparing the Interacting Boson Model with Configuration Mixing and the Extended Consistent-Q formalism;* J.E. Garcia-Ramos and K. Heyde.

Physical Review C77 (2008), 064324; *Configuration mixing in the neutron-deficient $^{186\text{-}196}Pb$ isotopes;* V. Hellemans, S. De Baerdemacker and K. Heyde.

Physical Review C (2009), in print; *Microscopic calculation of symmetry-projected nuclear level densities;* K. Van Houcke, S. Rombouts, K. Heyde and Y. Alhassid.

Physical Review C (2009), in print; *Spectral properties of a tractable collective Hamiltionian;* S. De Baerdemacker, K. Heyde and V. Hellemans.

Physical Review Letters (2009), submitted in 2008; *Shape coexistence near the neutron number N=20: first identification of the E0 decay from the deformed 0^{+}_{2} state in ^{30}Mg;* W. Schwerdtfeger, P.G. Thirolf, K. Wimmer, D. Habs, H. Mach, T.R. Rodriguez, V. Bildstein, J.L. Egido, L.M. Fraile, R. Gernhauser, R. Hertenberger, K. Heyde, P. Hoff, H. Hubel, U. Koster, T. Kroll, R. Krucken, R. Lutter, T. Morgan and P. Ring.

Physics Letters B (2009), submitted in 2008; *Evolution of the one-phonon $2^{+}_{1,ms}$ mixed-symmetry state in N=80 isotones as a local measure for the proton-neutron interaction;* T. Ahn, L. Coquard, N. Pietralla, G. Rainovski, K. Heyde, A. Costin, R.V.F. Janssens, C.J. ster, M. Carpenter and S. Zhu.

Reviews of Modern Physics (2009), submitted in 2009; *Magnetic dipole excitations in atomic nuclei: elementary modes of nucleonic motion;* K. Heyde, P. von Neumann-Cosel and A. Richter.

Reviews of Modern Physics (2008-2009), in preparation; *Shape coexistence in atomic nuclei;* K. Heyde and J.L. Wood.

b. List of co-publications

Frontiers in Nuclear Structure, Astrophysics and Reactions, AIP Conference Proceedings 1012(2008), 291 (ISBN-978-0-7354-0532-5) (K.U.Leuven – U.Gent – U.Köln – CSNSM – GNAIL - GSI)
Coulomb excitation of the N=50 nucleus ^{80}Zn; J.Van de Walle, F.Aksouh, F.Ames, F.Azaiez, T.Behrens, V.Bildstein, A.Blazhev, J.Cederkall, E.Clement, T.E.Cocolios, T.Davinson, P.Delahaye, J.Eberth, A.Ekstrom, D.V. Fedorov, V.Fedoseyev, L.Fraile, S.Franchoo, R.Gernhauser, G.Georgiev, D.Habs, K.Heyde, G.Huber, M.Huyse, F.Ibrahim, O.Ivanov, J.Iwanicki, J.Jolie, O.Kester, U.Koster, T.Kroll, R.Krucken, M.Lauer, A.F.Lisetsky, R.Lutter, B.A.Marsh, P.Mayet, O.Niedermaier, T.Nilsson, M.Pantea, O.Perru, R.Raabe, P.Reiter, M.Sawicka, H.Scheit, G.Schrieder, D.Schwalm, M.D.Seliverstov, T.Sieber, G.Sletten, N.Smirnova, M.Stanoiu, I.Stefanescu, J.-C.Thomas, J.J.Valiente-Dobon, P.Van Duppen, D.Verney, D.Voulot, N.Warr, D.Weisshaar, F.Wenander, B.H.Wolf and M.Zielinska.

Journal of Physics G 34 *(2008)* 014041, 1-6 (K.U.Leuven – U.Gent – U.Köln)
Gamow–Teller transitions in exotic pf-shell nuclei relevant to supernova explosion; Fujita Y., Rubio B., Adachi T., Molina F., Algora A., Berg G., von Brentano P., Buscher J., Cocolios T., De Frenne D., Fransen C., Fujita H., Fujita K., Gelletly W., Gentens J., Hatanaka K., Huyse M., Ivanov O., Koudriavtsev I., Jacobs E., Jordan D., Nakanishi K., Negret A., Pauwels D., Perez-Cerdan A., Pietralla N., Podolyak Z., Popescu L., Raabe R., Sakemi Y., Sawicka M., Shimbara Y., Shimizu Y., Shizuma T., Tameshige Y., Tamii A., Van den Bergh P., J Van de Walle J., Van Duppen P., Yosoi M., Zell K. *(Cit: 0)*.

Nuclear Instruments & Methods in Physics Research B 266 *(2008)* 4493-4497; (K.U.Leuven – GSI)
Online test of the FRS Ion Catcher at GSI; Petrick M., Plass W., Behr K., Brunle A., Caceres L., Clark J., Di Z., Elisseev S., Facina M., Fettouhi A., Geissel H., Huller W., Huyse M., Karagiannis C., Kindler B., Knobel R., Koudriavtsev I., Kurcewicz J., Levant T., Litvinov Y., Lommel B., Maier M., Morrisswy D., Munzenberg G., Portillo M., Savard G., Scheidenberger C., Van Duppen P., Weick H., Winkler M., Zabransky B..

Nuclear Instruments & Methods in Physics Research B 266 *(2008)* 4652-4656; (K.U.Leuven – GSI)
Beta-decay studies with an implantation technique; Büscher J., Ponsaers J., Raabe R., Huyse M., Van Duppen P., Aksouh F., Smirnov D., Fynbo H., Hyldegaard S., Diget C..

Nuclear Physics A 801 (2008) 83-100; (ULB – U.Köln)
Lifetimes of intruder states in ^{186}Pb, ^{188}Pb and ^{194}Po; T. Grahn, A. Dewald, O. Möller, R. Julin, C.W. Beausang, S. Christen, I.G. Darby, S. Eeckhaudt, P.T. Greenlees, A. Görgen, K. Helariutta, J. Jolie, P. Jones, S. Juutinen, H. Kettunen, T. Kröll, R. Krücken, Y. Le Coz, M. Leino, A.-P. Leppänen, ..., M. Bender and P.-H. Heenen.

Nuclear Physics A (2009), in print (ULB – U.Gent)
Criticallity in the configuration-mixed Interacting Boson Model: (II)Q(χ)Q(χ) mixing; V. Hellemans, P. Van Isacker, S. De Baerdemacker and K. Heyde.

Nuclear Sciences & Engn. 160 (2008) 200 - 206 (U.Gent – SCK°CEN)
Measurement of the ^{236}U(n,f) cross section in the neutron energy region from 0.5 eV up to 25 keV; C. Wagemans, L. De Smet, S. Vermote, J. Heyse, J. Van Gils, O. Serot.

Physical Review C (2009), in print (ULB – U.Gent)
Spectral properties of a tractable collective Hamiltionian; S. De Baerdemacker, K. Heyde and V. Hellemans.

Physical Review C 76 (2007) 045804, 1 – 8 (U.Gent – SCK°CEN)
Experimental determination of the $^{26}Al(n,\alpha)^{23}Na$ reaction cross section and calculation of
the Maxwellian-averaged cross section at stellar temperatures; L. De Smet, C. Wagemans, J. Heyse, J. Van Gils, J. Wagemans.

Physical Review C 77, 064313 (2008) (K.U. Leuven – GSI – CSNSM – U. Köln)
New sub-μs isomers in $^{125,127,129}Sn$ and isomer systematics of $^{124–130}Sn$; R. L. Lozeva, G. S. Simpson, H. Grawe, G. Neyens, L. A. Atanasova, D. L. Balabanski, D. Bazzacco, F. Becker, P. Bednarczyk, G. Benzoni, N. Blasi, A. Blazhev, A. Bracco, C. Brandau, L. C´aceres, F. Camera, S. K. Chamoli, F. C. L. Crespi, J.-M. Daugas, P. Detistov, M. De Rydt, P. Doornenbal, C. Fahlander, E. Farnea, G. Georgiev, J. Gerl, K. A. Gladnishki, M. G´orska, J. Gre¸bosz, M. Hass, R. Hoischen, G. Ilie, M. Ionescu-Bujor, A. Iordachescu, J. Jolie, A. Jungclaus, M. Kmiecik, I. Kojouharov, N. Kurz, S. P. Lakshmi, G. Lo Bianco, S. Mallion, A. Maj, D. Montanari, O. Perru, M. Pf¨utzner, S. Pietri, J. A. Pinston, Zs. Podoly´ak, W. Prokopowicz, D. Rudolph, G. Rusev, T. R. Saitoh, A. Saltarelli, H. Schaffner, R. Schwengner, S. Tashenov, K. Turz´o, J. J. Valiente-Dob´on, N. Vermeulen, J. Walker, E. Werner-Malento, O. Wieland, and H.-J. Wollersheim.

Physical Review C77 (2008), 064324 (ULB – Ugent)
Configuration mixing in the neutron-deficient $^{186-196}Pb$ isotopes; V. Hellemans, S. De Baerdemacker and K. Heyde.

Physical Review C, Nuclear physics 78 *(2008)* 047301; (K.U.Leuven – CSNSM – U.Köln)
Coulomb excitation of 68/28Ni40 at “safe” energies; Bree N., Stefanescu I., Butler P., Cederkall J., Davinson T., Delahaye P., Eberth J., Fedorov D., Fedosseev V., Fraile L., Franchoo S., Georgiev G., Gladnishki K., Huyse M., Ivanov O., Koster U., Kroll T., Krucken R., Marsh B., Niedermaier O., Reiter P., Scheit H., Schwalm D., Sieber T., Van de Walle J., Van Duppen P., Warr N., Weisshaar D., Wenander F., Zemlyanoy S. *(Cit: 0)*.

Physical Review C 79 (2009), 014309 (K.U.Leuven – U.Gent – CSNSM - IKP Köln –GSI –GANIL)
Low energy Coulomb excitation of neutron-rich Zn isotopes; J. Van de Walle, F. Aksouh, F. Ames, F. Azaiez, T. Behrens, V. Bildstein, J. Cederkall, E. Clement, T.E. Cocolios, T. Davinson, P. Delahaye, J. Eberth, A. Ekstrom, D.V. Fedorov, V. Fedoseyev, L. Fraile, S. Franchoo, R. Gernhauser, G. Georgiev, D. Habs, K. Heyde, G Huber, M. Huyse, F. Ibrahim, O. Ivanov, J. Iwanicki, J. Jolie, O. Kester, U. Koster, T. Kroll, R. Krucken, M. Lauer, A.F. Lisetsky, R. Lutter, B.A. Marsh, P. Mayet, O. Niedermaier, M. Pantea, R. Raabe, P. Reiter, M. Sawicka, H. Scheit, G. Schrieder, D. Schwalm, M.D. Seliverstov, T. Sieber, G. Sletten, N. Smirnova, O. Sorlin, M. Stanoiu, I. Stefanescu, J.-C. Thomas, J.J. Valiente-Dobon, P. Van Duppen, D. Verney, D. Voulot, N. Warr, D. Weisshaar, F. Wenander, B.H. Wolf and M. Zielinska

Physical Review C 79 (2009) 015801, 1-7 (ULB – CSNSM)

Low-energy ^{18}F(p,□)^{15}O cross section measurements relevant to □nova -ray emission;
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